

# **Power Distribution System for the Central Tracker Digital Front End Components**

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## **Abstract**

The DFE motherboards (DFEM) are versatile data acquisition boards used to process discriminator data from the Central Fiber Tracker, Central Pre-Shower, and Silicon detectors. DFE motherboards are 6U x 320mm boards with a custom backplane. Each motherboard supports up to two daughterboards; each daughterboard can contain up to 5 Xilinx FPGAs. Since most of the logic on the board is user-defined through the firmware, the power consumption is design dependent. In this document worst-case estimates are used.

## **Scope of this Document**

This document deals with the hardware needed to supply power to the various flavors of DFE subracks.

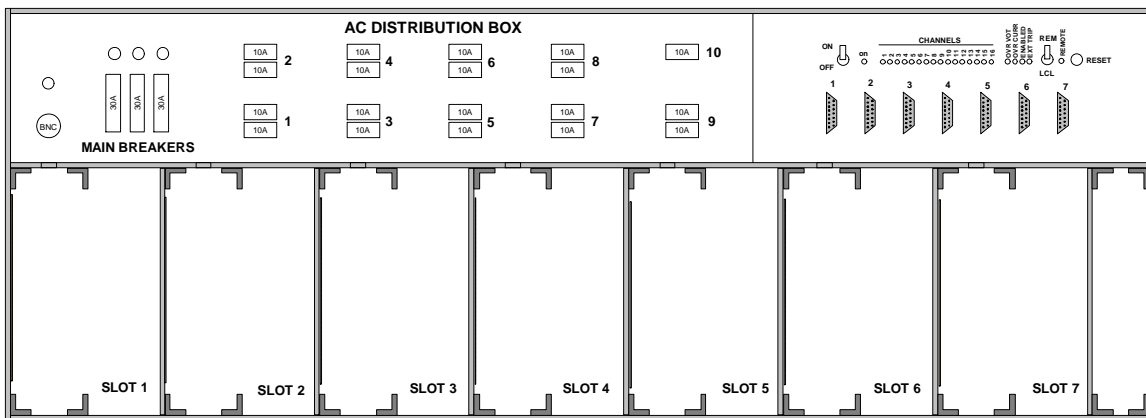
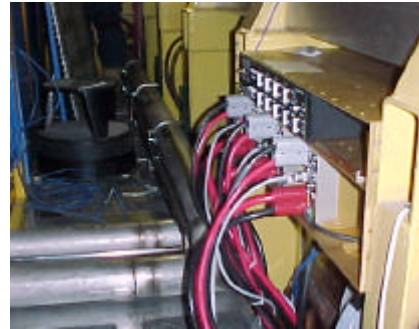
## **Location of Equipment**

Power supply chassis boxes are installed on the center platform directly behind racks PC03/PC04 and PC19/PC20. DFE Subracks powered by the chassis box are in PC03, PC04, PC19, and PC20.

## Power Supply Chassis

The DFE power supplies are located in a large aluminum chassis box located on the wall behind racks PC03/PC04 and PC19/PC20 on the center platform. SVX sequencer power supplies, which are similar to the DFE power supplies, also reside in these two chassis boxes.

The chassis box is constructed out of 1/8" anodized aluminum. A good ground connection is assured by connecting aluminum pieces together using star washers. Furthermore, the chassis is electrically connected to a good electrical ground with a tin plated copper braid.



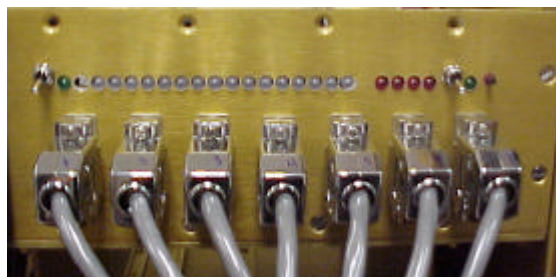
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Up to seven power supplies can be slid into bays located in the chassis box. The front of each bay is open, allowing power cabling to exit the chassis box. The open front also allows the power supply assembly to be disconnected and easily removed for maintenance.

Above the bays there is an enclosed area that is used for the AC distribution box and the monitoring interface boards. A small panel contains LEDs and switches that can be used to control the power supplies locally.



ABOVE: chassis front view with power supply assembly in slot 2.



UPPER RIGHT: Detail of chassis control panel.

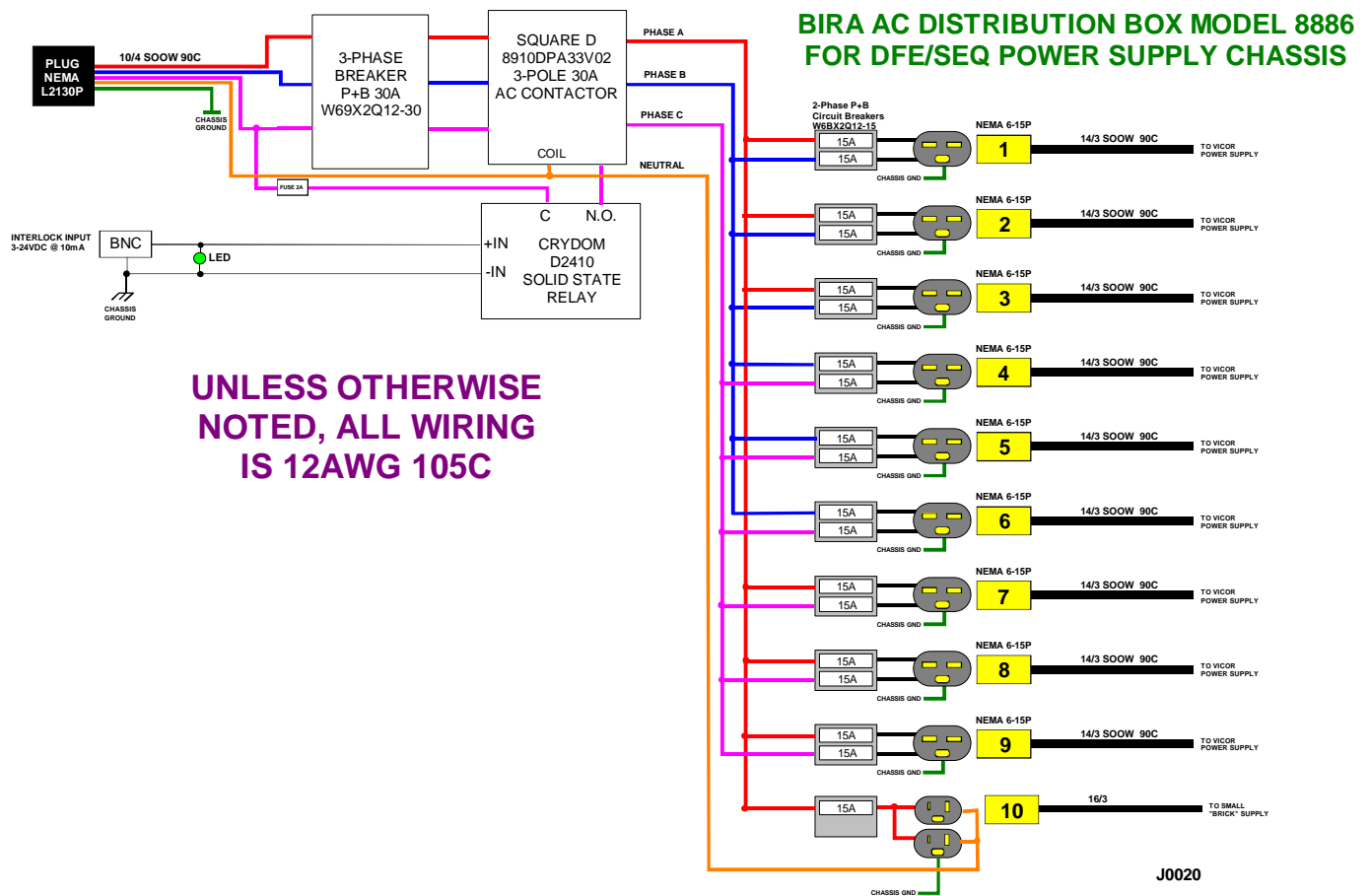


LOWER RIGHT: chassis with top lid removed. AC distribution box also has its lid removed.

## AC Distribution

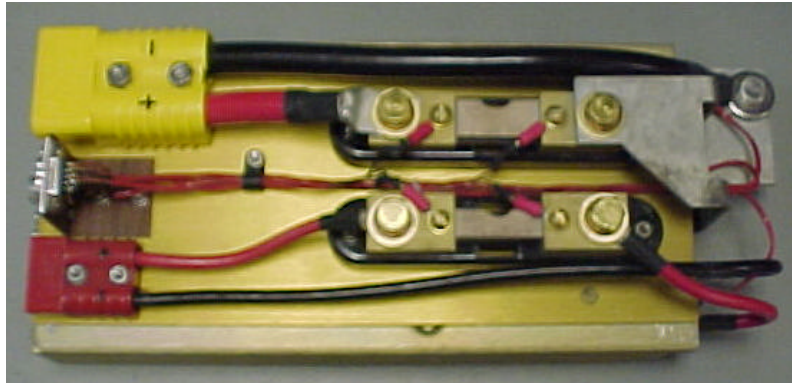
BiRa Systems built the AC distribution box to our specifications. It is a 3U x 19" rack mount unit with circuit breakers on the front panel and AC sockets on the back side. Three phase AC is supplied to the box, and is then distributed as two phase AC to the power supplies. A dual receptacle single phase AC connection is also available. Each AC receptacle is individually controlled with a circuit breaker. Additionally, the distribution box contains a relay to control all of the AC outputs; this relay is connected to the interlock system and requires 3-24 VDC @ 10mA to enable the AC outputs. The three phases are evenly distributed to nine two-phase outlets to allow for load balancing.

The schematic diagram of the AC distribution box is shown below:



## PFC Mini Power Supply

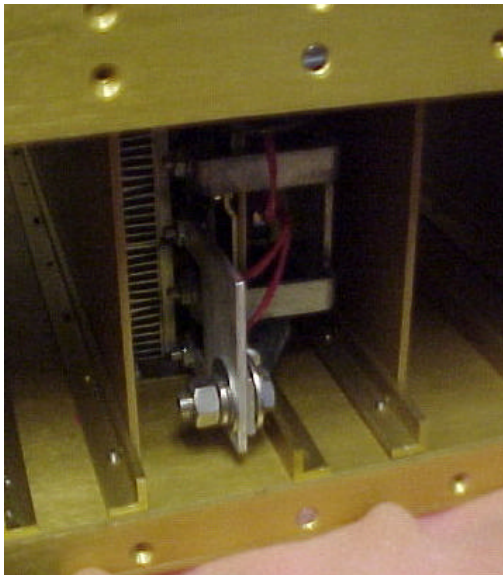
The power supply selected for the DFE subracks must be capable of delivering +3.3V @ 160A and +5.0V @ 40A to the DFE backplane. The Vicor PFC Mini supply meets these criteria and does so in a very low profile form factor. The supply consists of three modules: two +3.3V outputs each rated for 80A, and a +5V module rated for 40A. Two +3.3V modules (master and slave) are ganged together at the supply; internally these modules communicate with each other to support dynamic load sharing. All module outputs are fully isolated and feature automatic over-current and over-voltage shutdown.



Since the PFC mini supply does not report output current, external shunts were added to the back side of the supply. The +3.3V and +5.0V shunts are rated for 200A and 100A respectively. Current limiting resistors are used on the connections to the shunt terminals to protect the small wires connecting the shunt to the monitor connector.

Remote sensing is used to compensate for the voltage drop across the shunts and cables. Each PFC mini is air cooled using two very small high velocity fans. To facilitate airflow through the supply the front and back of the chassis box have been left open.

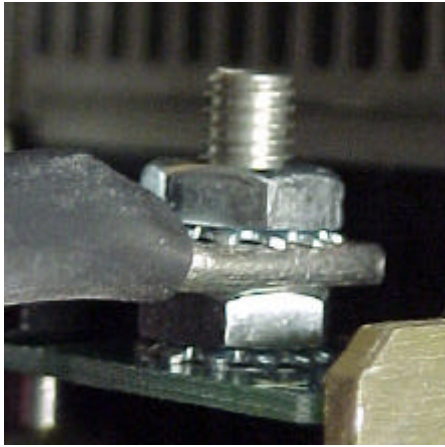
The bus connecting the master and slave outputs is constructed of 1/8" tin plated copper, 1.25" wide.



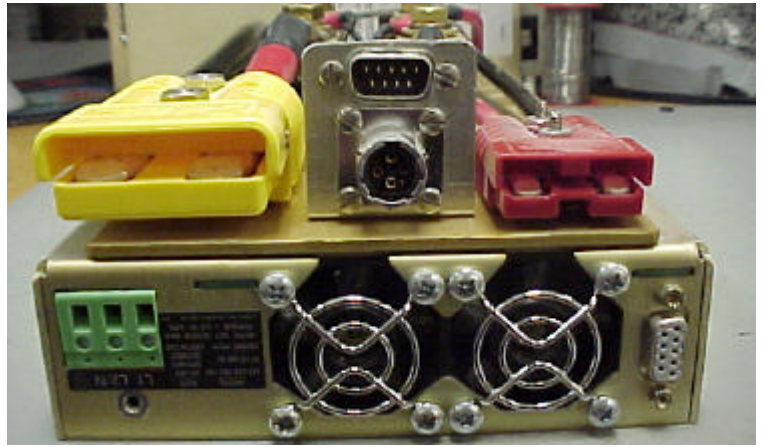
LEFT: back view of chassis showing airflow opening.

RIGHT: power supply rear view showing bus bars connecting the master and slave +3.3V modules. The +5V module is wired directly with 8 AWG.

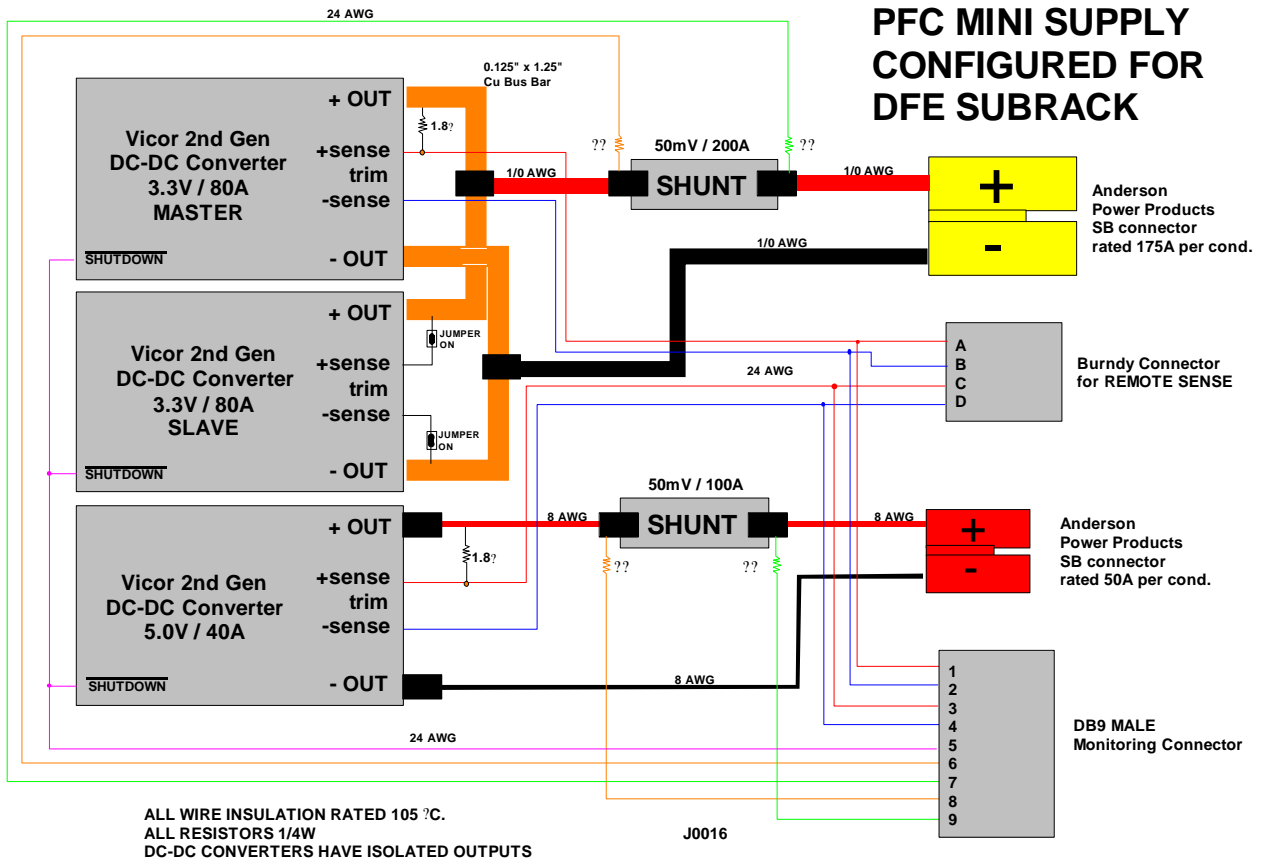




ABOVE: detail of +5V lug to the output of the power supply module.



RIGHT: front view of power supply assembly showing power output, remote sense, and monitoring connectors.



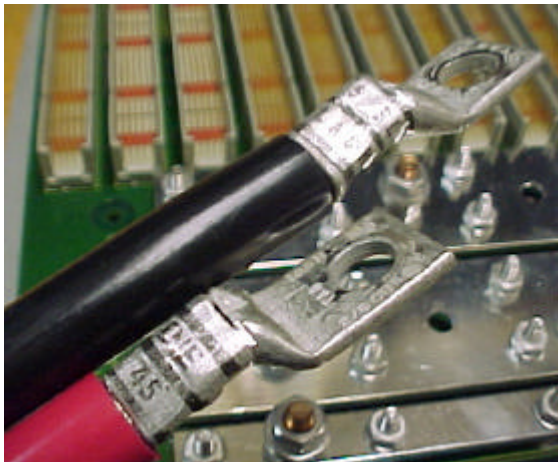
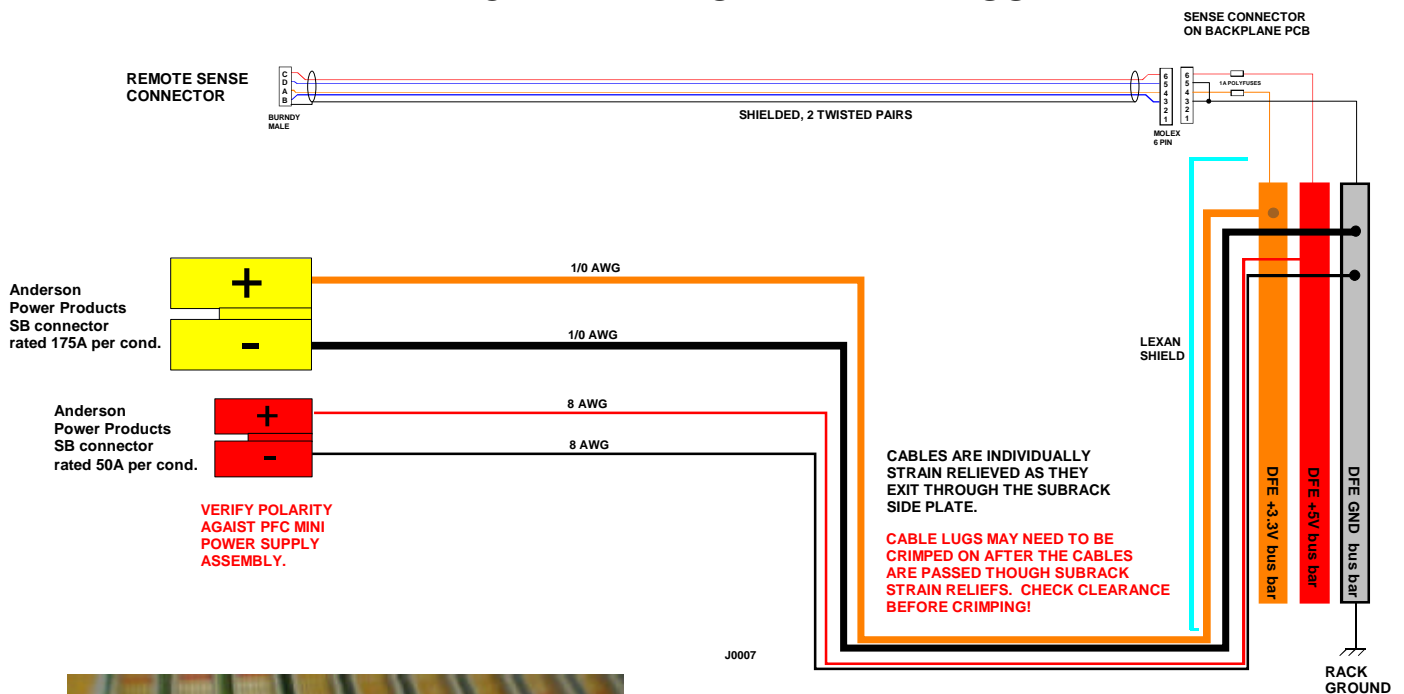


## DC Distribution

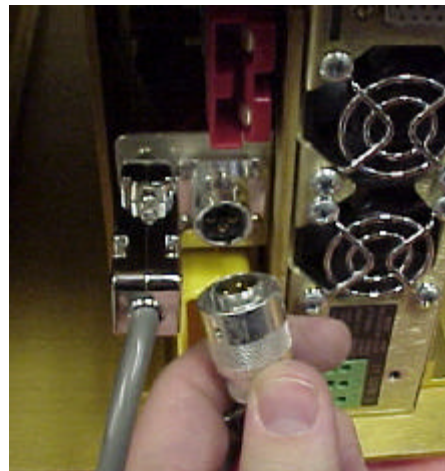
Since the power supplies are located on the wall behind the racks, the power cables must drop down, go under the aisleway, and back up inside the rack to the backplanes. Worst case distance is approximately 12 feet. To protect against shorts at the backplane, a lexan shield is placed over the bus bars. Additionally, the sense leads are protected with re-settable 1A polyfuses.

Power and remote sense cables are shown below.

### DFE BACKPLANE POWER HARNESS

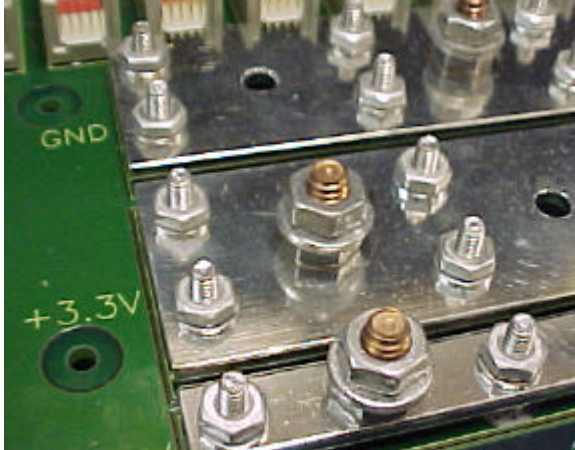


ABOVE: 1/0 cable and lugs used for +3.3V supply/return



## DFE Backplane

Three bus bars are used to distribute power on the DFE backplane. The two largest bus bars are for the +3.3V and GND; each bus bar is 1.5" x 0.125" tin plated copper. The +5V bus bar measures 0.75" x 0.125".



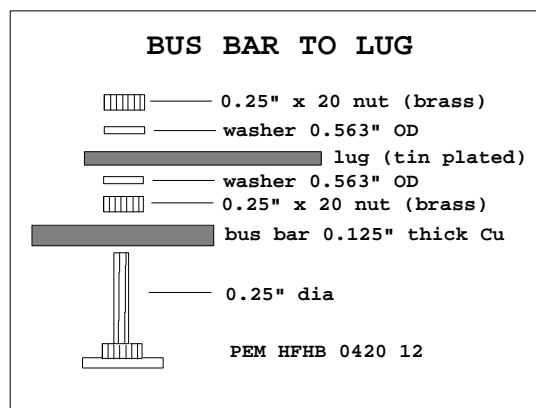
LEFT: DFE backplane bus bars and studs  
ABOVE: DFE backplane installed in subrack.  
Note lexan shield protecting the bus bars.

### Current Density – BUS BARS

$$\begin{aligned} +3.3V \text{ bar:} & \quad 160A / [(1.5'')(0.125'')] = 850 \text{ A} / \text{in}^2 \\ +5V \text{ bar:} & \quad 40A / [(0.75'')(0.125'')] = 425 \text{ A} / \text{in}^2 \\ GND \text{ bar:} & \quad 200A / [(1.5'')(0.125'')] = 1050 \text{ A} / \text{in}^2 \end{aligned}$$

*Exceeding the 1000 A / in<sup>2</sup> is acceptable in this case because of the large (1.5" x 17") surface area of the GND bus bar.*

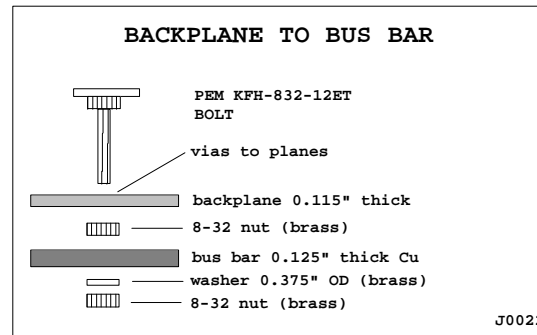
### Current Density – LUG to BUS BAR



$$\text{Area of washer} = (3.14)(0.282'')^2 - (3.14)(0.125'')^2 = 0.200 \text{ in}^2$$

$$\text{Current Density} = 160A / (0.200 \text{ in}^2) = 800 \text{ A} / \text{in}^2$$

## Current Density – Bus Bar to Top Pad of Backplane



The surface area of an 8-32 hex nut can be approximated using an outer diameter of 0.55" and an inner diameter of 0.375". Therefore...

$$\text{Area of nut} = (3.14)(0.275'')^2 - (3.14)(0.1875'')^2 = 0.127 \text{ in}^2$$

For the +3.3V bus bar there are 18 nuts. The current density is:

$$160\text{A} / [(18 \text{ nuts})(0.127 \text{ in}^2 / \text{nut})] = 70 \text{ A} / \text{in}^2$$

The GND bus bar also has 18 nuts. The current density here is:

$$200\text{A} / [(18 \text{ nuts})(0.127 \text{ in}^2 / \text{nut})] = 87 \text{ A} / \text{in}^2$$

Finally, the +5 bus bar has 9 nuts. The current density is:

$$40\text{A} / [(9 \text{ nuts})(0.127 \text{ in}^2 / \text{nut})] = 35 \text{ A} / \text{in}^2$$

*These numbers are very conservative since they assume that no current is flowing through the shaft of the bolt.*



### Current Density – Top Backplane Pad to Inner Power Layers

At each stud 1 large (0.150") thru-hole and 12 small (0.0276") vias connect the bus bar to the internal power layers of the backplane. The +3.3V and GND bus bars each have 18 studs; the +5V bus bar has 9 studs. The total area through which current flows is calculated as follows:

Area = (thru hole diameter)(3.14)(thickness of copper plane)(number of layers)

$$\text{Area of large thru hole} = (0.150'')(3.14)(0.0014'')(2) = 0.0013 \text{ in}^2$$

$$\text{Area of 12 small vias} = (.0276'')(3.14)(0.0014'')(2)(12) = 0.0029 \text{ in}^2$$

If the +3.3V bus bar has 18 studs, then the total area is  $18[0.0013 + 0.0029] = 0.076 \text{ in}^2$

$$160\text{A} / 0.076 \text{ in}^2 = 2100 \text{ A} / \text{in}^2$$

Likewise, the GND bus bar also has 18 studs, yielding a current density of:

$$200\text{A} / 0.076 \text{ in}^2 = 2600 \text{ A} / \text{in}^2$$

Finally, the +5V bus bar has 9 studs for a total area of  $0.038 \text{ in}^2$  and a current density of

$$40\text{A} / 0.038 \text{ in}^2 = 1000 \text{ A} / \text{in}^2$$

*In this case the  $1000\text{A} / \text{in}^2$  guideline can be exceeded because the large surface area of the backplane and its ability to dissipate heat.*

### Current Density – Internal Power Layers in the Backplane

There are 2 +3.3V and 2 GND layers in the DFE backplane. There is only a single +5V plane layer. Each layer is 1oz copper – a total thickness of 0.0014". The width of each plane is 16.5". Therefore, the current density in the cross sectional area of the power planes is:

$$+3.3\text{V: } 160 \text{ A} / [(2 \text{ layers})(16.5'')(0.0014''/\text{layer})] = 3500 \text{ A} / \text{in}^2$$

$$\text{GND: } 200 \text{ A} / [(2 \text{ layers})(16.5'')(0.0014''/\text{layer})] = 4300 \text{ A} / \text{in}^2$$

$$+5\text{V: } 40 \text{ A} / [(1 \text{ layer})(16.5'')(0.0014''/\text{layer})] = 1700 \text{ A} / \text{in}^2$$

*In this case the  $1000\text{A} / \text{in}^2$  guideline can be exceeded because the large surface area of the backplane and its ability to dissipate heat.*

### Current Density – Backplane Pins

All Hard Metric backplane pins are rated for 1A.

+3.3V	31 pins	$(160\text{A}/\text{crate}) / [(20 \text{ cards}/\text{crate})(31 \text{ pins}/\text{card})]$	= 260 mA / pin
+5V	6 pins	$(40\text{A}/\text{crate}) / [(20 \text{ cards}/\text{crate})(6 \text{ pins}/\text{card})]$	= 330 mA / pin
GND*	106 pins	$(200\text{A}/\text{crate}) / [(20 \text{ cards}/\text{crate})(106 \text{ pins}/\text{card})]$	= 100 mA / pin

\* includes shield pins.

## Monitoring

Each PFC mini assembly has two outputs: +3.3V and +5V. For the purposes of monitoring, these outputs are considered separate entities— thus each chassis box can contain up to 14 outputs that must be monitored. A monitor board supports up to 8 supplies; therefore two monitor boards must be used in each chassis box. Slot assignments are shown in the tables below:

PC 20 / PC 19 CHASSIS					
slot	supply	circuit breaker	DB15 connector	OUTPUT#1	OUTPUT#2
1	SEQ PC20 UPPER	1	1	5.0V 160A	5.2V 80A
2	SEQ PC20 LOWER	2	2	5.0V 160A	5.2V 80A
3	SEQ PC19 UPPER	3	3	5.0V 160A	5.2V 80A
4	SEQ PC19 LOWER	4	4	5.0V 160A	5.2V 80A
5	DFE PC20	5	5	3.3V 160A	5.0V 40A
6	DFE PC19	6	6	3.3V 160A	5.0V 40A
7	<unused>	n/a	n/a	n/a	n/a

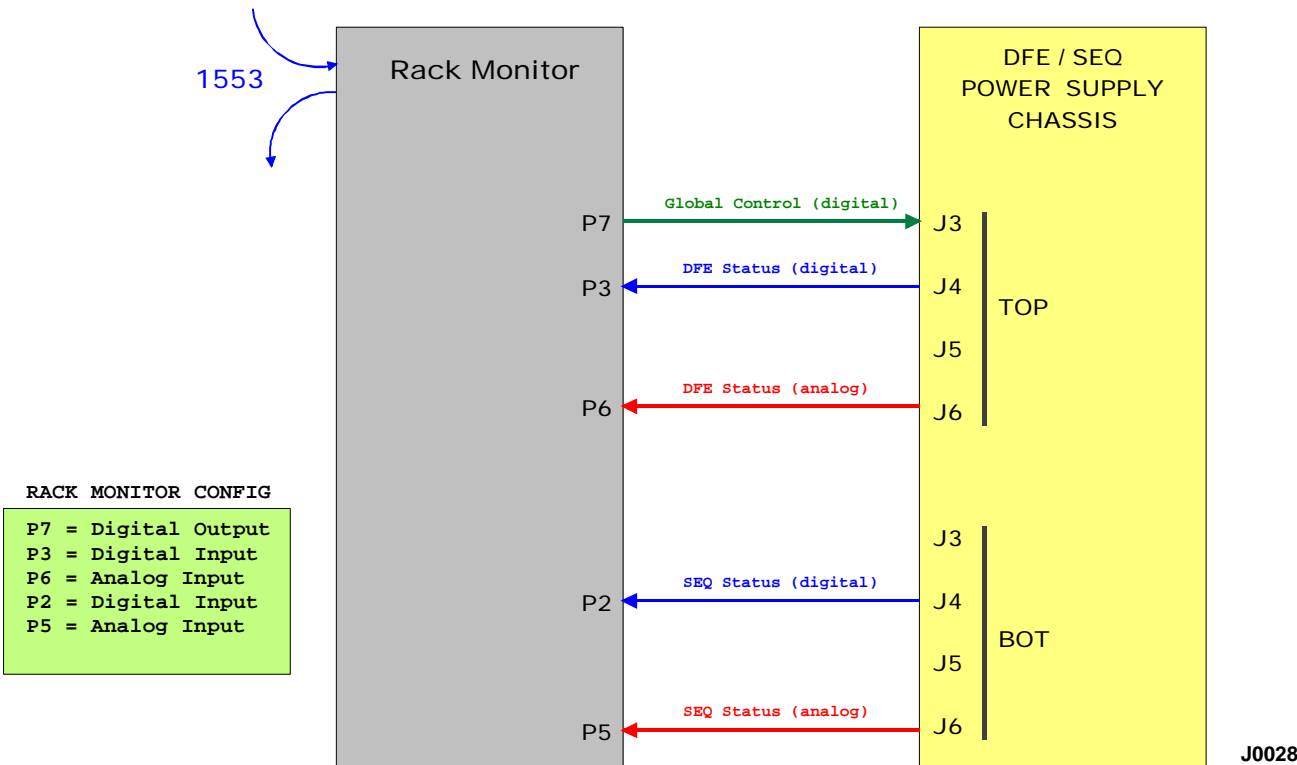
PC 03 / PC 04 CHASSIS					
slot	supply	circuit breaker	DB15 connector	OUTPUT#1	OUTPUT#2
1	SEQ PC03 UPPER	1	1	5.0V 160A	5.2V 80A
2	SEQ PC03 LOWER	2	2	5.0V 160A	5.2V 80A
3	SEQ PC04 UPPER	3	3	5.0V 160A	5.2V 80A
4	SEQ PC04 LOWER	4	4	5.0V 160A	5.2V 80A
5	DFE PC03 UPPER	5	5	3.3V 160A	5.0V 40A
6	DFE PC03 LOWER	6	6	3.3V 160A	5.0V 40A
7	<unused>	n/a	n/a	n/a	n/a

Monitor boards are powered by a small switcher supply contained in the upper compartment of the chassis box. This little supply is powered by the AC distribution box, which is controlled by the Interlock system. If for any reason power is removed from the Interlock BNC connector on the AC distribution box all power supplies *and* the monitor boards will shut down.

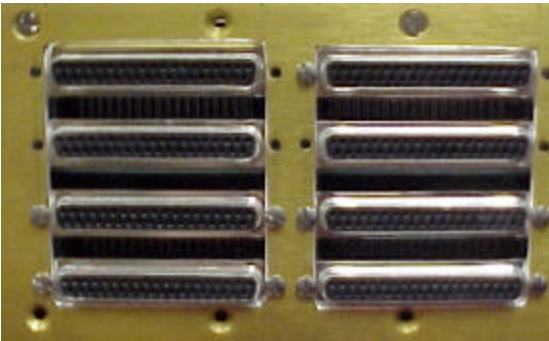
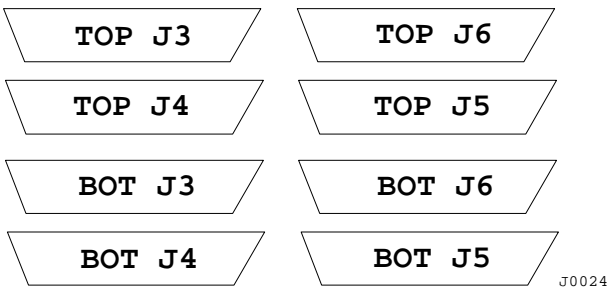
The monitor board has the capability to shut down all supplies in the chassis box. Individual supplies cannot be turned on or off. Shutdown can happen locally (using the switches on the front panel of the power supply chassis box) or remotely through the rack monitor. Note that when the PFC mini supply is shut down the fans continue to run.

Monitor boards buffer analog inputs such as current and voltage and send them to the rack monitor. The monitor boards also check for over-voltage and over-current conditions and shut down *all* of the supplies in the chassis when over-voltage or over-current conditions exist. To clear the trip and enable the supplies, press the reset button (if local) or assert the RESET line (if Remote).

A total of 5 cables are used to connect the power supply chassis to a rack monitor as shown below:



For more information on how the power supply chassis will appear to the rack monitor, see engineering note 2001-02-16a.



connector	pin	description	type	comment
J3 TOP	1	Supply Output Enable (Enabled=1 / Disabled=0)	digital in	controls all supplies
J3 TOP	2	RESET (Reset=1)	digital in	controls all supplies
J3 TOP	3-16	unused digital input	digital in	
J3 TOP	17-19	no connect	n.c.	
J3 TOP	20-35	GND	GND	
J3 TOP	36-37	no connect	n.c.	

connector	pin	description	type	comment
J4 TOP	1	Supply Output Status (Enabled=1 / Disabled=0)	digital out	same as J4 BOT pin 1
J4 TOP	2	Operating Mode Status (Remote=1 / Local=0)	digital out	same as J4 BOT pin 2
J4 TOP	3-4	unused digital output	digital out	
J4 TOP	5	DFE supply, slot 5, +5V (secondary) trip=1	digital out	
J4 TOP	6	DFE supply, slot 5, +3.3V (primary) trip=1	digital out	
J4 TOP	7	DFE supply, slot 6, +5V (secondary) trip=1	digital out	
J4 TOP	8	DFE supply, slot 6, +3.3V (primary) trip=1	digital out	
J4 TOP	9-13	unused digital output	digital out	
J4 TOP	14	Reset status (Reset=1)	digital out	same as J4 BOT pin 14
J4 TOP	15	DFE OverVoltage status (Trip=1)	digital out	DFE supplies ONLY
J4 TOP	16	DFE OverCurrent status (Trip=1)	digital out	DFE supplies ONLY
J4 TOP	17-19	no connect	n.c.	
J4 TOP	20-35	GND	GND	
J4 TOP	36-37	no connect	n.c.	

connector	pin	description	type	comment
J5 TOP	*	unused	*	do not connect

connector	pin	description	scale	type
J6 TOP	1	DFE supply, slot 5, +5V (secondary) voltage	1x	analog out
J6 TOP	2	DFE supply, slot 5, +5V (secondary) current	1V / 100A	analog out
J6 TOP	3	DFE supply, slot 5, +3.3V (primary) voltage	1x	analog out
J6 TOP	4	DFE supply, slot 5, +3.3V (primary) current	1V / 100A	analog out
J6 TOP	5	DFE supply, slot 6, +5V (secondary) voltage	1x	analog out
J6 TOP	6	DFE supply, slot 6, +5V (secondary) current	1V / 100A	analog out
J6 TOP	7	DFE supply, slot 6, +3.3V (primary) voltage	1x	analog out
J6 TOP	8	DFE supply, slot 6, +3.3V (primary) current	1V / 100A	analog out
J6 TOP	9-16	unused analog output	n/a	analog out
J6 TOP	17-19	no connect	n/a	n.c.
J6 TOP	20-37	GND	n/a	GND

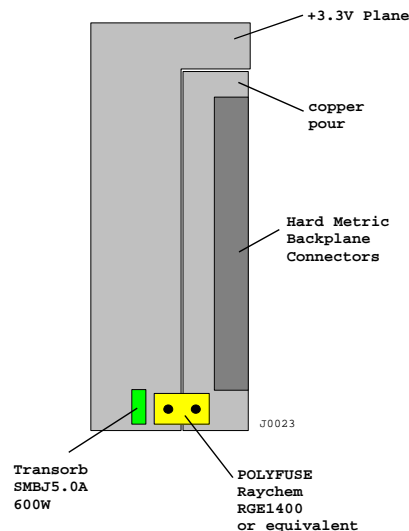
connector	pin	description	type	comment
J4 BOT	1	Supply Output Status (Enabled=1 / Disabled=0)	digital out	same as J4 TOP pin 1
J4 BOT	2	Operating Mode Status (Remote=1 / Local=0)	digital out	same as J4 TOP pin 2
J4 BOT	3-4	unused digital output	digital out	
J4 BOT	5	SEQ supply, slot 1, 5.2V (secondary) trip=1	digital out	
J4 BOT	6	SEQ supply, slot 1, +5V (primary) trip=1	digital out	
J4 BOT	7	SEQ supply, slot 2, 5.2V (secondary) trip=1	digital out	
J4 BOT	8	SEQ supply, slot 2, +5V (primary) trip=1	digital out	
J4 BOT	9	SEQ supply, slot 3, 5.2V (secondary) trip=1	digital out	
J4 BOT	10	SEQ supply, slot 3, +5V (primary) trip=1	digital out	
J4 BOT	11	SEQ supply, slot 4, 5.2V (secondary) trip=1	digital out	
J4 BOT	12	SEQ supply, slot 4, +5V (primary) trip=1	digital out	
J4 BOT	13	unused digital output	digital out	
J4 BOT	14	Reset status (Reset=1)	digital out	same as J4 BOT pin 14
J4 BOT	15	SEQ OverVoltage status (Trip=1)	digital out	SEQ supplies ONLY
J4 BOT	16	SEQ OverCurrent status (Trip=1)	digital out	SEQ supplies ONLY
J4 BOT	17-19	no connect	n.c.	
J4 BOT	20-35	GND	GND	
J4 BOT	36-37	no connect	n.c.	

connector	pin	description	scale	type
J6 BOT	1	SEQ supply, slot 1, 5.2V (secondary) voltage	1x	analog out
J6 BOT	2	SEQ supply, slot 1, 5.2V (secondary) current	1V / 100A	analog out
J6 BOT	3	SEQ supply, slot 1, +5V (primary) voltage	1x	analog out
J6 BOT	4	SEQ supply, slot 1, +5V (primary) current	1V / 100A	analog out
J6 BOT	5	SEQ supply, slot 2, 5.2V (secondary) voltage	1x	analog out
J6 BOT	6	SEQ supply, slot 2, 5.2V (secondary) current	1V / 100A	analog out
J6 BOT	7	SEQ supply, slot 2, +5V (primary) voltage	1x	analog out
J6 BOT	8	SEQ supply, slot 2, +5V (primary) current	1V / 100A	analog out
J6 BOT	9	SEQ supply, slot 3, 5.2V (secondary) voltage	1x	analog out
J6 BOT	10	SEQ supply, slot 3, 5.2V (secondary) current	1V / 100A	analog out
J6 BOT	11	SEQ supply, slot 3, +5V (primary) voltage	1x	analog out
J6 BOT	12	SEQ supply, slot 3, +5V (primary) current	1V / 100A	analog out
J6 BOT	13	SEQ supply, slot 4, 5.2V (secondary) voltage	1x	analog out
J6 BOT	14	SEQ supply, slot 4, 5.2V (secondary) current	1V / 100A	analog out
J6 BOT	15	SEQ supply, slot 4, +5V (primary) voltage	1x	analog out
J6 BOT	16	SEQ supply, slot 4, +5V (primary) current	1V / 100A	analog out
J6 BOT	17-19	no connect	n/a	n.c.
J6 BOT	20-37	GND	n/a	GND

## DFE Motherboard

DFE Motherboards require only a +3.3V power source. A resettable fuse is used to protect against shorts on the motherboard – the Raychem RGE1400 is rated for 14A, meaning it will hold a current of 14A without blowing. Worst case power estimates for the DFE motherboard with 2 CFT/CPS AXIAL daughterboards is 7A.

A 600W transorb is placed between the +3.3V and GND planes to protect against voltage spikes.



## DFE Transition Board

The Transition board requires +3.3V @ 1.5A and +5V @ 1.5A (worst case). Each transition board has two re-settable poly fuses, each rated for 4A. Two 600W transorbs are located on the “circuit side” of the polyfuses. PCB layout is similar to DFE motherboard.

## DFE Crate Controller

The DFEC board requires +3.3V @ 5A and +5V @ 5A (worst case). Each transition board has two re-settable poly fuses, each rated for 5A. Two 600W transorbs are located on the “circuit side” of the polyfuses. PCB layout is similar to DFE motherboard.